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Investigation of the consolidation drainage of high water content clay by siphon method through unsaturated filter

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Abstract

Recently, the disposal of dredged soil has become a worldwide problem. In order to utilize high water content soil material, it is essential to dewater and increase the soil strength. There are urgent demands for developing an alternative new method to dewater the dredged soils in more economical and environment friendly standpoint. Furthermore, by using adsorption effect of porous material such as granular blast furnace slag, there is possibility to establish purification technology of contaminated soil.

In this paper, the siphon method is proposed to dewater the high water content dredged soil with horizontally installed plastic board drain and filter material. In order to investigate the availability and effectiveness of this method, series of tests were conducted to investigate the dewatering behaviour and strength of dredged soil with vacuum and siphon methods by using different materials as filter, such as Toyoura sand, zeolite, granular blast furnace slag. High water content dredged soil can be consolidated by using siphon method with saturated filter material such as Toyoura sand. However, it was impossible to dewater dredged soil by using siphon method with unsaturated porous filter material. The water retention tests of soil by using centrifuge method was performed to clarify the mechanism of preventing consolidation dredged soil. The test cannot find an accurate soil-water retention curve of dredged soil because of volume change.

The water retention test by suction method was performed and clarify the mechanism that prevents consolidation dredged soil. The cause that prevents consolidation of dredged soil has been presumes by clarifying the air entry value. In addition, degree of saturation and suction in dredged soil and filter material has been clarified by using aquameters. The examination whether consolidation of dredged soil on various conditions focused on height of dredged soil and filter material is performed based on the revealed mechanism.

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1. Introduction

Recently, the disposal of the dredged soil has become a worldwide problem. Common problems that mostly appear when dealing with disposed dredged soil is due to its high content of water and its low strength. In order to utilize high water content soil material, it is essential to reduce the water content by dewatering, so the soil strength increases. Efficiency energy has become an urgent demand since several past years. More economical and environment friendly methods are required instead of using the conventional techniques which are costly and require more energy. Vacuum consolidation by siphon method is potentially become a good alternative to solve those problems.

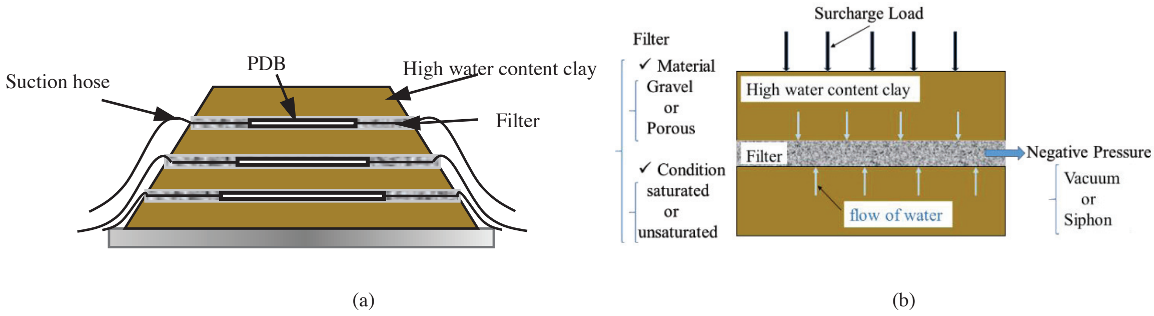


Fig.1 (a) Schematic illustration of embankment construction ;(b) A flow of the water in two layers of the clay and the filter.

In order to utilize the dredged soil as high strength material, high-strengthening of cement treated clay by mechanical dehydration was developed [1]. On the other hand, in order to purify the water containing pollutants, porous materials such as natural zeolite are recently used as the countermeasure for water quality purification [2]. In addition, utilization of porous materials such as granular blast furnace slag (GBF-slag) that has latent hydraulic properties to the soil structures is also investigated [3].

Fig.1(a) shows the schematic illustration of embankment construction that possess the drainage and purification function by utilizing clean energy such as siphon method. As shown in this figure, by using adsorption effect of porous filter material such as zeolite, GBF-slag, there is some possibility to dewater the dredged soil and to establish purification technology of contaminated soil by the drainage water passing through the porous filter materials. In this study, it is essential to investigate flow of water from the high water content clay towards the filter material as shown in Fig.1(b). Various conditions of filter material need to take into account when applying vacuum or siphon method, such as the type of filter material (using granular or porous material) and the saturation condition of filter material (in saturated or unsaturated condition). In addition, it is important to clarify the behavior of combination surcharge load and negative pressure (by vacuum or siphon) that applied at the same time. By clarifying those condition explained above, and controlling the flow of water, it is possible to construct the embankment shown in Fig.1(a).

In this particular study, porous materials and a general particle material [4] were used as the filter materials for investigating the dewatering and adsorption effect. Siphon method is proposed to dewater the high water content dredged soil with horizontally installed plastic board drain and filter material. The availability and effectiveness of this method are discussed.

2. Consolidation Test By Siphon

2.1. Dredged soil and filter materials

As a representative of high water content clay, dredged soil from Kanmon route, Japan was used in this study. The dredged soil that passing through 2mm sieve was tested in this experiment. Table 1 summarizes the properties of dredged soil. The air entry value of clay is important to know the clay can be consolidated by air pressure or not. In this study, in order to investigate the air entry value of dredged soil, the water retention test was performed by using centrifuge method. Fig.2(a) shows the water retention curve of several clay and filter materials. The result shows that the air entry value of the dredged soil is about 0.1 kPa. This value became much smaller than that of Kaolin clay, and it is considered that this value is not so accurately obtained. The initial water content of the dredged soil was approximately 170%, thus the volume change due to centrifuge process become larger, and a suitable value might not be obtained [5]. It is necessary to clarify the proper value of air entry value by using other more reliable method than centrifuge test. For the filter material, GBF-slag and zeolite were chosen as porous materials which the pollutant adsorption effect could be expected. GBF-slag which is by-product generated during manufacturing process of iron and has processed the latent hydraulic properties to solidify response to water with time. Toyoura sand was also used as non-porous material for the filter material. The particle size distribution curves and the physical properties of filter materials are shown in Fig.2(b) and Table 2. As shown in the Table 2, it is clear that GBF-Slag and Zeolite have possessed some voids in particles.

Table1. Summary of properties for dredged soil

Soil particle density rs(g/cm^3)	Liquid limit (%)	Plastic limit (%)
2.697	95.00	35.91
Initial water content wini(%)	Initial void ratio eini	Compression index Cc
168.20	4.28	0.51

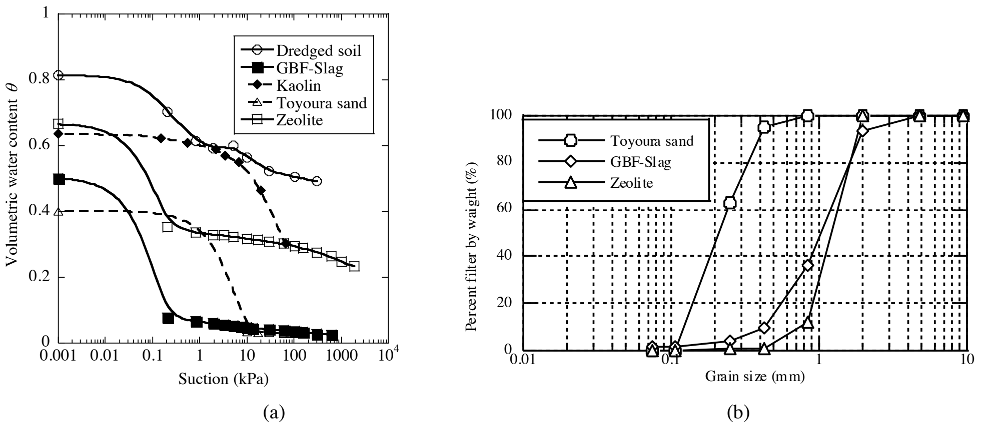


Fig.2 (a) Water retention curves of dredged soil and filter materials,(b) Particle size distribution curves of filter materials.

Table2. Physical properties of filter materials

	Toyoura sand	GBF-Slag	Zeolite
Density of soil particle ρ_s (g/cm^3)	2.64	2.75	2.36
Maximum void ratio e_{max}	0.97	1.52	2.42
Minimum void ration e_{mim}	0.61	0.99	1.78

2.2. Test method and procedure

The experiment container used in this study has approximately 49cm inside diameter as shown in Fig.3. Plastic Board Drain (PBD) which connected a tube was located at the bottom of the container. The filter material is compacted at 90% of degree of compaction around 5cm in height, and later, water is poured into the filter material from the bottom of the container to increase the filter saturation. Dredged soil was adjusted at in-site initial water content state

(w_{ini}=170%), then it was poured into the container to a height of 15cm with degassing. Consolidation drainage tests were performed by acting the negative pressure of siphon water head difference about 42.5kPa (4.25m). The experiments at the same negative pressure conditions using the vacuum pump were also performed.

2.3. Test results and discussions

Fig.4(a) shows the relationships between drainage amounts and elapsed time by using siphon and vacuum method. As shown in this figure, the consolidation drainage amount and elapsed time relationship curve using the principle of siphon is similar to that of the vacuum pump until around 24 hours. However, after around 24 hours, this relationship curve using siphon method has different tendency in comparison with that of the vacuum pump in the case of using Toyoura sand filter. This figure also shows kinds of filter material (Toyoura sand and GBF-slag) has little influence on the relationships between drainage amount and elapsed time by using vacuum method. In addition, in the case of condition that the filter (Toyura sand) is saturated, the quantity of water m_w existed the filter is consider to be equal to the void volume. m_w is defined as follows:

$$m_w = V_v \times \rho_w = \left\{ \left(1 - \frac{\frac{D_C}{100} \times \rho_{d\max}}{\rho_s} \right) \times V \right\} \times \rho_w \tag{1}$$

where V is the volume of filter, D_c(=90%) is degree of compaction , ρ_w(=1 g/cm^3)is unit weight of water.

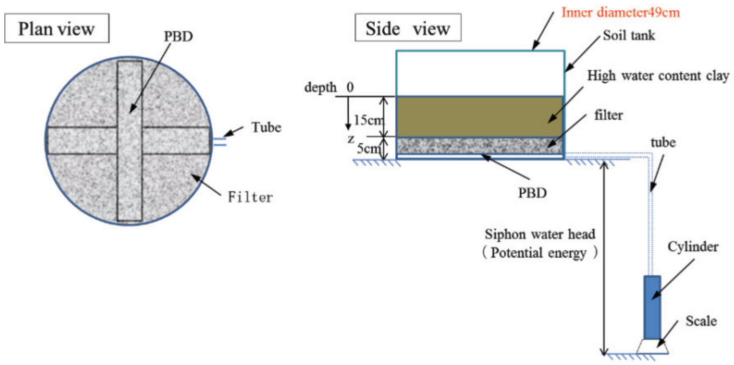
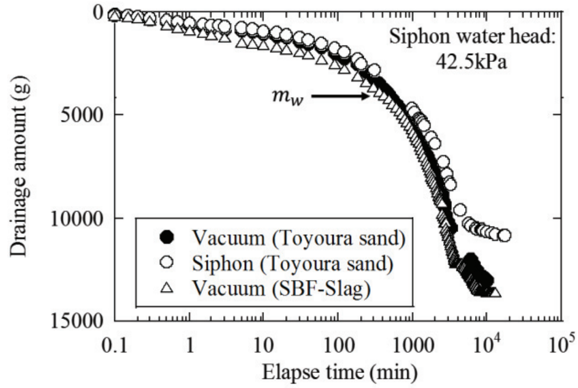
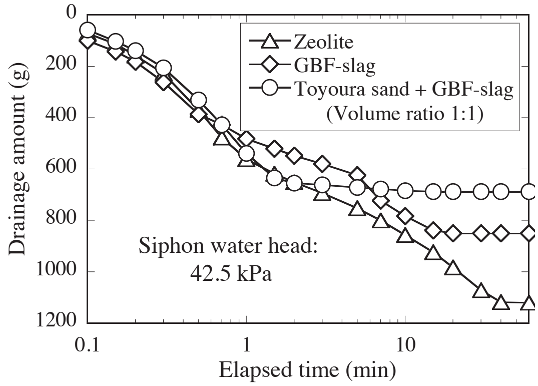


Fig.3.Consolidation test apparatus by siphon method.

The quantity of water in Toyoura filter mwToyoura is 4157.2 g obtained from Equation (1). As a result of calculation, compaction drainage of the clay is considered to be activated because the drainage volume is larger than the quantity of water included within the filter. In order to confirm the drainage performance of porous filter material by using siphon method, same consolidation tests were performed under different test conditions using porous filter materials. Fig.4(b) shows the relationships between drainage amount and elapsed time using different filter materials by siphon method. As shown in this figure, consolidation drainage initially occurred and later converged to the constant values at least until 60 min in all the filter material conditions. Even if the filter material which was mixed with Toyoura sand and porous material (GBF-slag) was used as a filter material, similar tendency was also indicated. It was clarified from the laboratory tests that it is impossible to dewater the high water content dredged soil by using siphon method with unsaturated porous filter material such as zeolite or granular blast furnace slag continuously. In the case of using porous materials as filter, there is some possibility to be an unsaturated condition of filter. It is necessary to investigate the saturation of filter material and differences of hydraulic conductivity between dredged soil and filter materials.



(a)



(b)

Fig.4. (a) The relationships between drainage amount with time of Toyoura filter. ; (b) The relationships between drainage amount with time of porous filter.

3. Consolidation Test by Siphon Method and Air Pressure

3.1 Test method and procedure

In order to investigate the proper use of porous filter materials, a small size consolidation test apparatus was prepared by using a new container of inner diameter 10cm in Fig.5(a).Fig.5(b) shows the way of the pressure of each test condition. Heights of the filter material and dredged soil and compaction procedure are unified with the former experiments. PBD was not set at the bottom of the filter material. Consolidation tests were performed under single drainage condition. GBF-slag was used as a filter material. Surcharge load is applied on the upper part of dredged soil by air pressure. In this testing, 5kPa, 47.5kPa by surcharge load and 5kPa by surcharge load with siphon method (42.5 kPa) were applied to the single layered specimens, respectively. Drainage amounts with elapsed time were measured. Table.3 shows experiment conditions.

Table.3 Experiment conditions.

	Surcharge Load (kPa)	Siphon (kPa)	Δσ (kPa)
case1	5	0	5
case2	47.5	0	47.5
case3	47.5	0	47.5
case4	5	42.5	47.5
case5	5	42.5	47.5

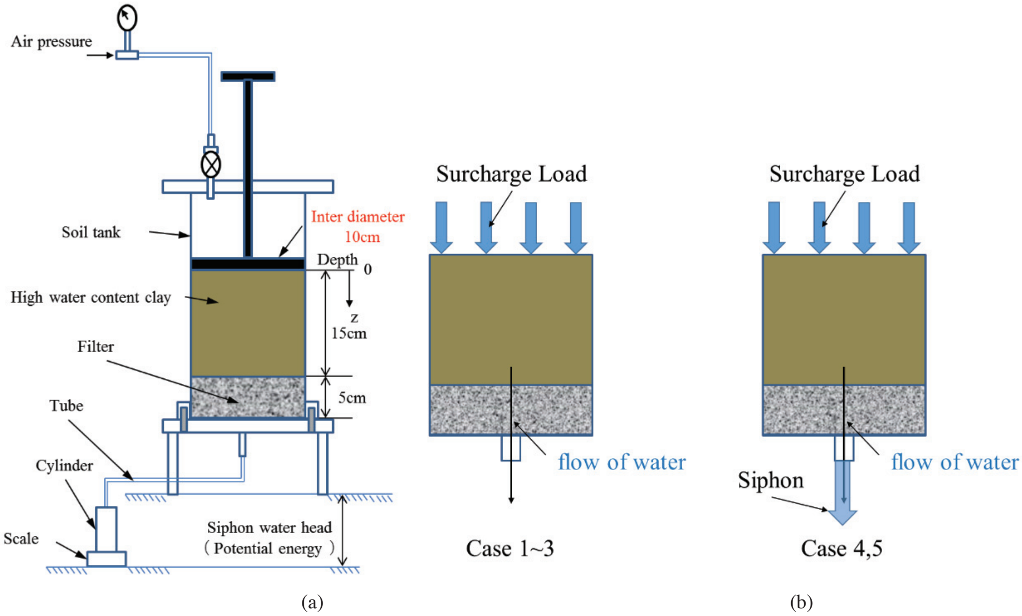


Fig.5.(a) Consolidation test apparatus by siphon method and air pressure.;(b) The way of the pressure of each test condition.

3.2 Test results and discussions

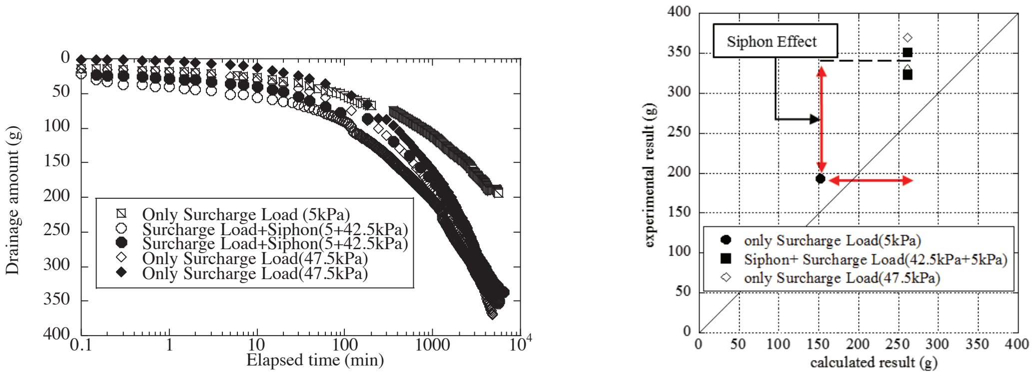
Fig.6(a) shows the relationships between consolidation drainage amount and elapsed time. In both cases that only 5kPa of surcharge load *p* and 5kPa of surcharge load *p* with siphon method (42.5kPa), consolidations were performed through the filter. It is considered that inflow of water from the dredged soil to the porous filter material were occurred by applying the surcharge load. Drainage amount and elapsed time relationship curve that surcharge load of 47.5 kPa is applied had different tendency in comparison with that of 5kPa of surcharge load with siphon method. However, the final consolidation drainage amount of 5 kPa of surcharge load with siphon method reached to the almost same value of 47.5 kPa of surcharge load. By combining siphon method and surcharge load, it was indicated the possibility to dewater the same amount of volume in the case of surcharge load *p*=47.5 kPa due to the functional recovery of siphon method. The calculation of the drainage amount was carried out. From the test results, the consolidation drainage amount of 5 kPa of surcharge load with siphon method became larger than that of only 5 kPa of surcharge load with time. A supposition includes the following things; the dredged soil is saturated because it is slurry, the settlement of the clay happens only by drainage, the drainage was carried out only from a base. The quantity of drainage water W_w is defined as follows:

$$\sigma' = \gamma' \times H = \left(\frac{\rho_s - \rho_w}{1 + e_{ini}} g_n \right) \times H \tag{2}$$

$$W_w = V_{Drainage} \times \rho_w = \left(S_f \times A \right) \times \rho_w = \left\{ \left(\frac{H}{1 + e_{ini}} C_c \log \frac{\sigma' + \Delta\sigma}{\sigma'} \right) \times A \right\} \times \rho_w \tag{3}$$

where g_n (=9.8 m/s^2) is gravitational acceleration, H(=0.075 m) is the height of clay, σ' is the initial effective stress of center of clay.

As a calculation, the initial effective stress σ' was 0.24(kPa) to target the center of the clay layer. Fig.6.(b) shows what compared the experimental result with the calculation result. It is revealed that the calculation underestimates quantity of settlement. It is the reason why drainage water may have not only water also clay and water in the filter flow out with drainage water.



(a) (b)

Fig.6.(a) The relationships between drainage amount with time using siphon method and surcharge load. ;(b) The relationship between experiment and calculation.

4. Conclusion

In this study, series of tests were conducted to investigate the dewatering behaviour of the dredged soil with vacuum and siphon methods by using different filter materials (Toyoura sand, zeolite, granular blast furnace slag). The main conclusions obtained from this study are as follows;

1) High water content dredged soil can be consolidated by using siphon method with saturated filter material such as Toyoura sand. The effectiveness for dewatering by siphon method is almost equal to that of vacuum consolidation method in the view point of reducing the volume.
2) It is impossible to dewater the high water content dredged soil by using siphon method with unsaturated porous filter material such as zeolite or granular blast furnace slag continuously. However, by using siphon method with surcharge load, there is some possibility to dewater the dredged soils.

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